Lake Ohinewai pest fish removal

CBER Contract Report 120

By

Adam J. Daniel

Dai K. J. Morgan

Prepared for Waikato Conservancy, Department of Conservation.

Centre for Biodiversity and Ecology Research
Department of Biological Sciences
School of Science and Engineering
The University of Waikato
Private Bag 3105
Hamilton, New Zealand

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Email: carpresearch@gmail.com

THE UNIVERSITY OF WAIKATO
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CBER University of Waikato
Centre for Biodiversity and Ecology Research

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Reviewed by: *Approved for release by*:

Brendan Hicks
University of Waikato

David Hamilton
University of Waikato

Executive summary

Most riverine lakes in the Waikato region have deteriorated from a macrophyte-dominated state to an algal-dominated state. Pest fish have further compounded water quality issues by resuspending nutrient-rich sediment and are believed to be a major barrier to water quality improvements. The University of Waikato has an ongoing programme funded by the Ministry of Business, Innovation and Environment, to produce pest fish management tools for end users that include removing pest fish from five lakes as an objective. The goal of the fish removals is to test the assumption that removing pest fish will improve water quality. Lake Ohinewai was selected as one of the five lakes to attempt a pest fish removal in 2009 and the removal operation was scheduled for January 2011. The Department of Conservation agreed to assist with funding for consumables and the construction of an experimental barrier to assist with the Lake Ohinewai removal project. University of Waikato staff began removing pest fish from Lake Ohinewai in January 2011 with the assistance of the Department of Conservation and volunteers. A one-way fish barrier was designed and installed during May 2011 to prevent adult pest fish from recolonising the lake.

Overall, 2.7 t of pest fish were removed from Lake Ohinewai including 60% of the koi carp population. The biomass of koi carp was reduced from 240 kg ha^{-1} to below 100 kg ha^{-1}. The combined initial biomass of goldfish (18.9 kg ha^{-1}), catfish (13.1 kg ha^{-1}) and rudd (6.5 kg ha^{-1}) were less than 16% of the 241 kg ha^{-1} estimated for koi carp. The final goldfish biomass (7.4 kg ha^{-1}) indicated a 61% reduction and catfish biomass was reduced by 42% to approximately 7.6 kg ha^{-1}. The length frequency of pest fish found in Lake Ohinewai indicated a relatively uniform size distribution for most pest species with the exception of rudd where only large adults were captured. Although gambusia were present in the lake in large numbers no estimate of biomass or removal were conducted.

Shortfin eels were abundant in Lake Ohinewai, but the diversity of native fish was surprisingly poor. Aside from 800 shortfin eels captured, only 18 longfin eels were caught. All native fish were released after capture.

Overall, the removal phase of the operation was highly successful, yielding valuable information for future pest fish removal operations. The University of Waikato will continue fish removal efforts and long-term water quality monitoring to evaluate the impact of pest fish on water quality. Initial water quality measures have been encouraging but inconclusive.

1. Introduction

Water quality in the Waikato region has been in rapid decline since the 1970s (Chapman 1996) and most of the formerly stable oligotrophic lakes in the region have reverted to stable eutrophic or hypereutrophic states. The introduction of common carp *Cyprinus carpio* (hereafter referred to as koi carp) in the Waikato region during the 1980s (Pullan 1984) further compounded impacts of existing pest fish populations, including goldfish (*Cyprinus auratus)*, catfish (*Ameiurus nebulosus)*, rudd (*Scardinius erythrophthalmus)* and tench (*Tinca tinca).*

New Zealand koi carp are genetically very similar to common carp and very comparable behaviourally (Daniel et al. 2011). Common carp are one of the most prolific and damaging invasive fish species in the world (Lougheed et al. 1998; Zambrano et al. 1999). The feeding activity of common carp disrupts and softens sediments, which are then easily resuspended by wind-waves (Scheffer 2004). The combination of resuspended sediment and carp excretion transfer nutrients into the water column (Lamarra 1975; Cline et al. 1994). Low light penetration caused by suspended sediment and algal blooms can greatly reduce or eliminate macrophytes (Van Dijk and Van Donk 1991; Parkos et al. 2003), causing a shift from a macrophyte-dominated to an algal-dominated equilibrium similar to the shifts that have occurred in may Waikato lakes since the 1970s.

In theory, reducing koi carp biomass should dramatically reduce sediment resuspension, allow sediment to reconsolidate and reduce algal blooms by decreasing bioavailable nutrients. Pond studies have shown that a 70-75% reduction of common carp biomass can restore water quality (Lougheed et al. 1998; Zambrano et al. 1999). However, percent biomass is highly subjective considering the potential for variability in population densities. Bajer et al. (2009) observed a biomass dependant effect of common carp in a shallow North American lake that indicated a threshold of approximately 100 kg ha^{-1} at which vegetation and waterfowl use dramatically decreased.

Our objective at Lake Ohinewai was to restore water quality by conducting as many pest fish as possible with the underlying goal of reducing koi carp biomass to below 100 kg ha^{-1}. Success of the operation was to be judged in terms of the koi carp biomass reduction and long term water quality improvements. Native fish including shortfin, *Anguilla dieffenbachii,* and longfin, *Anguilla australis*, eels were to be captured and released to conduct a biomass estimate. This report will cover the evaluation of the removal effort and the results of short term water quality monitoring. The Department of Conservation had the added objective of creating a permanent but experimental adult pest fish barrier to prevent the rapid recolonisation of the lake by pest fish.

2. Study Site

Lakes Ohinewai is a riverine lake located 7 km north of Huntly on the eastern side of the Waikato River. The lake surface area is 16.8 ha with a 331 ha catchment and has the lake has a single drain that leads to Lake Waikare (Figure 1). Lake Ohinewai deteriorated form a stable oligotrophic state (macrophyte dominated) to a stable eutrophic (algal dominated) state during the early 1990s (DoC staff personal communication) and currently lacks aquatic macrophytes. In 1981, 80% of the lake was covered in aquatic macrophytes and by 1991 none remained (Edwards et al. 2005). Figure 1 shows a good example of the relatively common algal bloom that persists for most of the summer months. The catchment is dominated by intensive pastoral farming but also has minor residential development.

Figure 1. Map of Lake Ohinewai (picture from http://maps.google.co.nz).

The substrate of Lake Ohinewai is relatively coarse compared to surrounding lakes and is predominantly sand. The existing damage caused by koi carp is extensive with >95% of the substrate disrupted to approximately 20 mm deep (Figure 2A). Roughly calculated, this would be the equivalent of 3,172 m^3 of sediment being resuspended over an unspecified amount of time. Despite the degradation, native mussels (Figure 2B) and eels still persist in the lake.

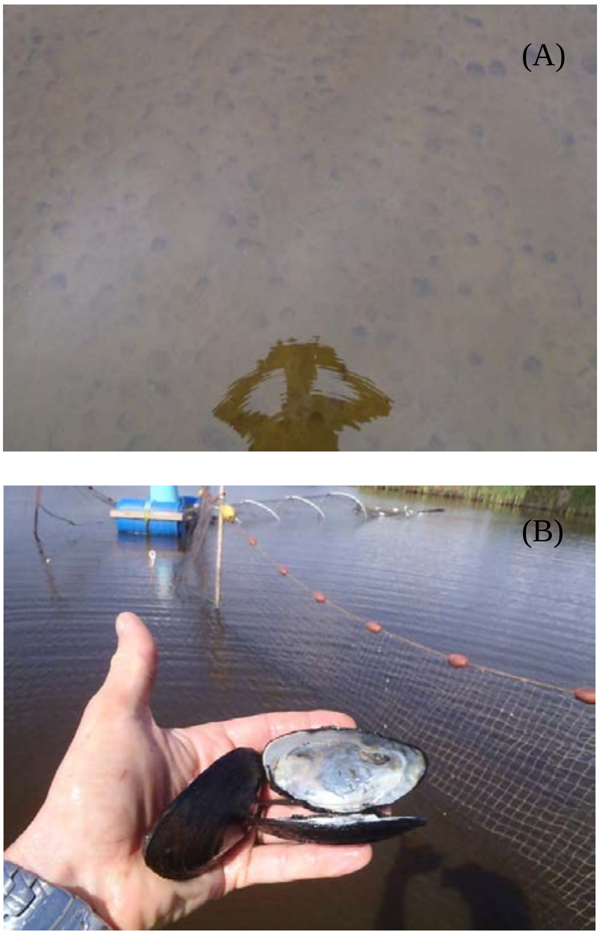

Figure 2. (A) Approximately one meter square plot with intense koi carp (*Cyprinus carpio*) damage on the western shore of Lake Ohinewai. (B) Two adult freshwater mussels from the western shore of Lake Ohinewai. Photos: A. Daniel.

3. Methods

Collection and marking

Fish were marked using left pectoral fin clips (eels, rudd, goldfish and koi carp) or dorsal spine removal (catfish) and released on the western end of the lake (17-19 January 2011). A subset of all species was weighed and fork length measured. Fish handling and aesthetic use were as described in (Daniel et al. 2009). Fish were captured for marking and removal (24 January to 2 May 2011) using fyke nets, minnow traps, electrofishing, beach seining and baited traps. Bow fishing was trialled for fish removal in drains where other methods were not effective. Electrofishing was conducted using a total of 34 separate 20-min sampling periods (11 during marking and 23 during the removal phase) and concentrated on productive shallow-water habitat near the shore (Figure 3A). Boat electrofishing methods were as described in Hicks et al. (2006). Forty fyke nets were set from 17-19 January (marking) and 24-28 January (removal) for a total of 240 net nights. Fyke nets were cleared daily and sites were distributed evenly throughout the lake (Figure 3B). Seining was conducted using a purpose built 100-m seine (40-mm mesh size) that was hand-pulled from the western shore of the lake. Baited and unbaited fish traps were used from 24 January until 2 May for a total of 85 net nights. Traps were placed in five locations (Figure 3b) but were limited to relatively shallow locations (>2 m) due to the wall height of the traps (2 m). All non-native fish were removed from the lake and donated to a fertiliser processor while native fish were released.

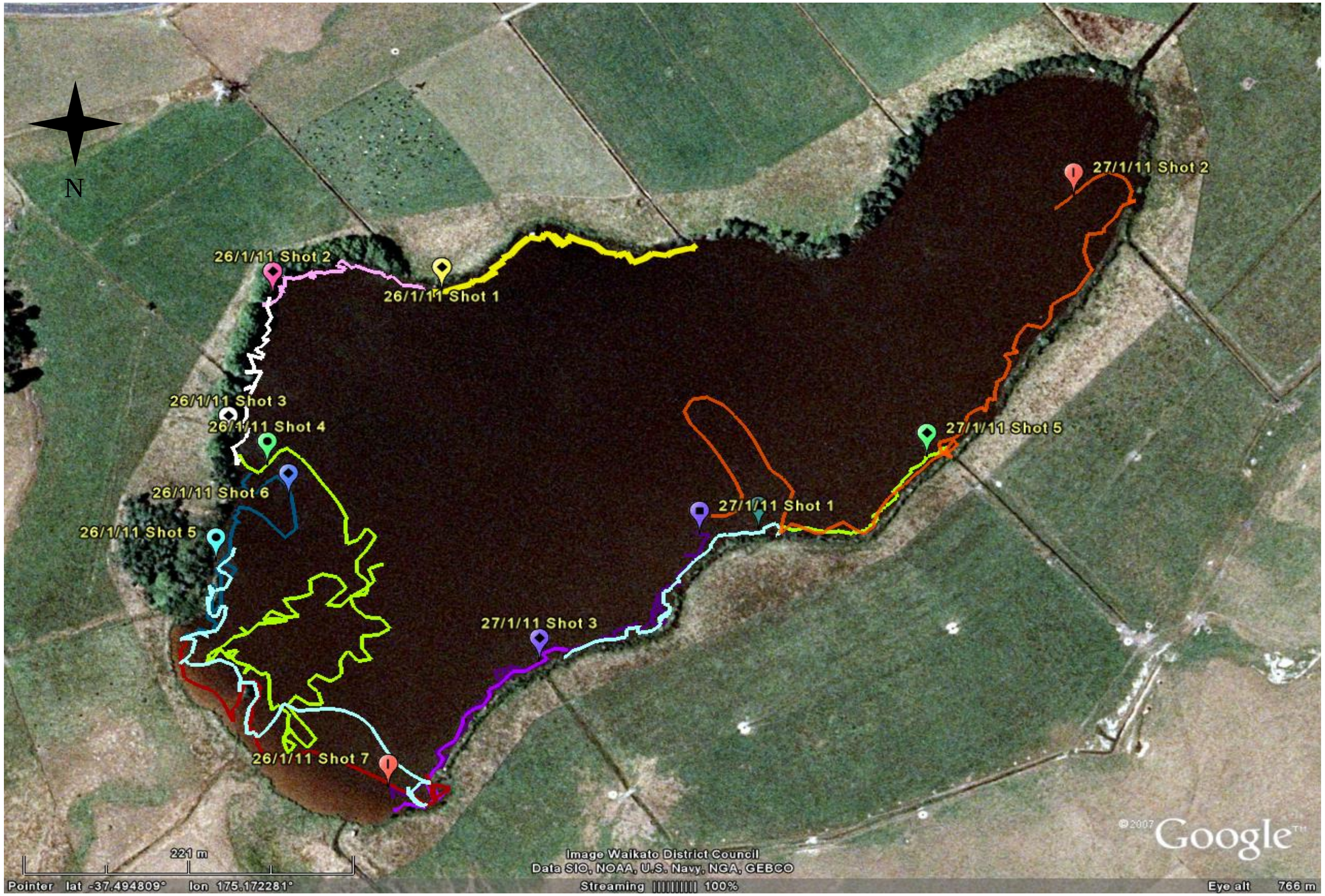

Figure 3. (A) Boat electrofishing tracks in Lake Ohinewai 17-28 January 2011.

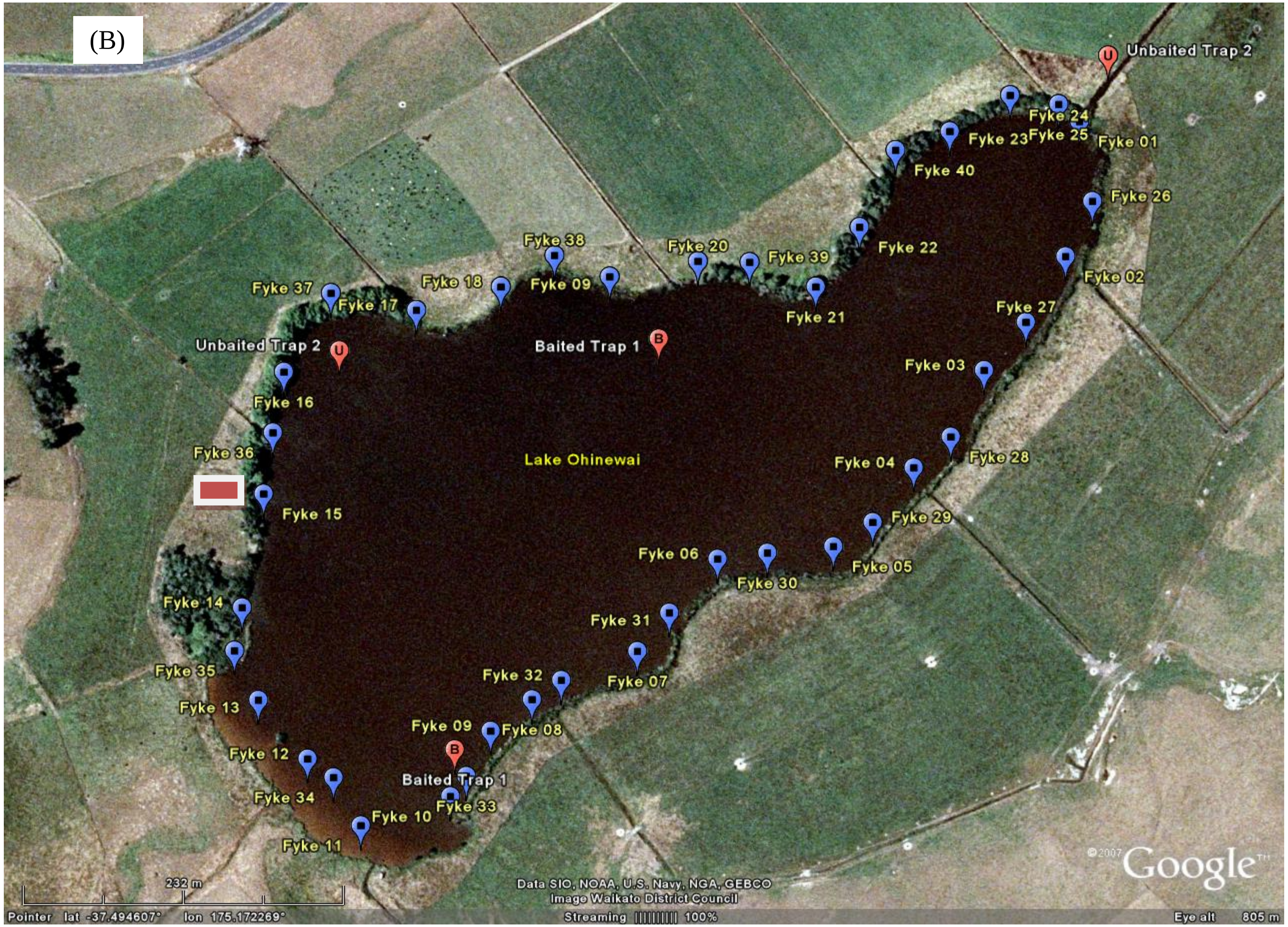

Figure 3. (B) Fyke net set locations (blue dots) at Lake Ohinewai 17-28 January 2011; trap locations (red dots and square) 24 January to 2 May 2011.

Traps were set in various formations (Figure 4A, 4B and 4C) to determine the most productive configuration including baited and unbaited sets. Traps were also placed in the drain and used in conjunction with larger pen nets. Pen traps consisted of a 0.1-ha enclosure (Figures 4B) with two one-way doors (Figures 4C), two feeders, and two traps located in on the outer corners of the pen.

Figure 4. (A) Koi trap with fish feeder Lake Ohinewai western shore April 2011. (B) Koi carp pen trap and (C) a close up picture of the one-way gate on the pen trap with blue feeder barges in the background on the western shore of Lake Ohinewai April 2011. Photos: A. Daniel.

Biomass estimates

To satisfy the assumptions of a Lincoln-Petersen mark recapture study (closed population) the fish population sampled at Lake Ohinewai was isolated using a temporary barrier in the drain consisting of 30-mm mesh netting. Population estimates were calculated using the Lincoln-Petersen method using the programme Mark-recapture (Jungck 2011). Biomass estimates calculated are for fish >75 mm due to the bias of sampling methods toward larger fish. Due to the length of the recapture operation (>90 days) fin clips became indistinguishable from fin injury due to fin regrowth by the end of the third month of removals (Figure 5). Accordingly, population estimate was based on data collected during the first three months of the removal operation (24 January to 31 March 2011). The initial biomass was based on the average fish weight (kg) multiplied by the population estimate. The final biomass was calculated by subtracting the actual biomass removed from the initial biomass estimate. Due to breaches of the barrier caused by debris, movement of fish in the drain were monitored using fyke nets from 3-13 April 2011. Monitoring was halted due to the theft of a fyke net from the drain. Due to the installation of the one-way barrier, biomass estimates should be considered maximums as it is likely some fish left the lake and were unable to return.

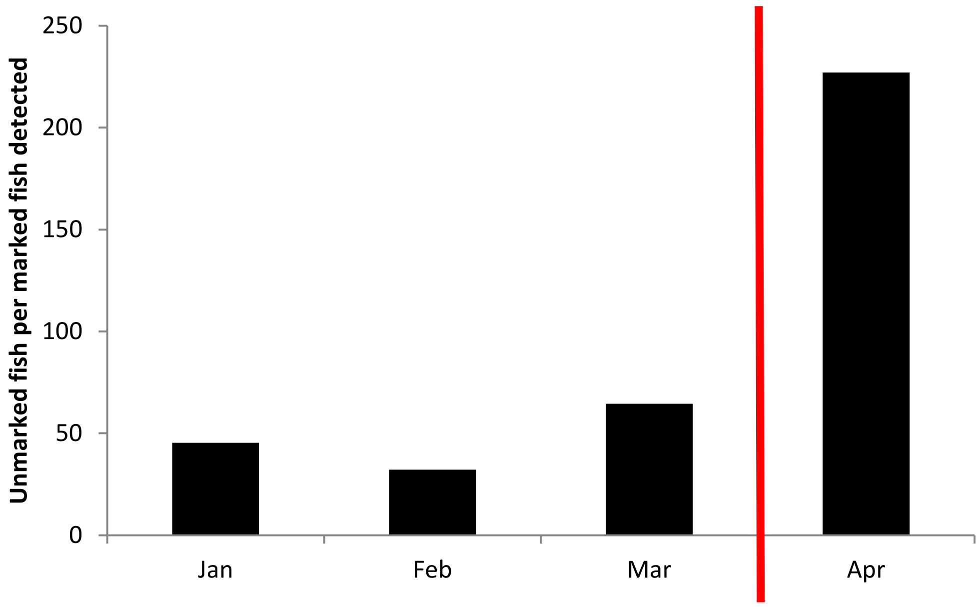

Figure 5. Number of unmarked koi carp removed for every marked koi carp (*Cyprinus carpio*) detected monthly at Lake Ohinewai, 2011. Data to the left of the red line was used to produce the population estimate due to difficulties identifying marked fish after 30 March 2011.

Catch per unit effort

Catch per unit effort (CPUE) was calculated to compare fishing methods used to remove pest fish at Lake Ohinewai. Bycatch of native fish was also monitored to help improve selective fishing methods for pest fish. CPUE is based on one day of work for a team of two; this included a one-night set of 40 fyke nets, a day of boat electrofishing, clearing two traps, or a day of bowfishing. This estimate is based on what was achieved on average during the Lake Ohinewai removal and is not the optimal CPUE for each method.

Water quality methods

Water quality data was collected weekly from 16 February to 4 May 2011 from the same location (New Zealand Map Grid E2702498, N6409669) as close to 12:00 h as possible. This location was selected as it was used by the Waikato Region Council for their lake monitoring programme. Prior to 16 February, an alternative location (E2702296, N640697) 205 m away was used.

Lake depth at the sampling location was measured using a depth sounder (Eagle Z-5000). Dissolved oxygen and water temperature measurements were taken at 0.5 m intervals from the lake surface using a held-held water sampler (YSI Sonde 600QS); although, only 0.5 m and 2.0 m data are presented here as there was little difference between measurements throughout the water column. Dissolved oxygen calibrations were conducted on the day measurements were taken. Secchi disc depth measurements were taken from the sunniest side of the boat and were the mean of the depth the disc went out of view as it was lowered through the water column, and the depth that it was again visible when raised. Measurements were conducted again if these two values were > c.10%.

Water samples were also collected at 0.9 m and 2.7 m using a 10-L Schindler's trap. Two water samples were taken from each depth and 2.5 L of each were transferred into different 5-L acid-washed containers (one container for 0.9 m and other for 2.7 m depth samples). These samples were then kept on ice until we were able to get back to the shore where total and volatile suspended solids and chlorophyll *a* samples were prepared. On the shore, 1 L of water from the 0.9-m and 2.7-m marked containers were transferred to different sterile bottles and kept on ice until they could be analysed for total and volatile suspended solids concentrations (g m^{-3}) using standard protocols (APHA2540D, APHA2540E). To prepare the chlorophyll *a* sample, a known quantity of water from the 0.9-m container was passed through a 45-µm glass filter (Advantec GC-50) and then the filter was folded into aluminium foil. This was then stored on ice before being frozen until concentrations (ug L^{-3}) could be analysed through acetone extraction. Two samples were prepared per sampling, and the mean concentration was calculated. Historic water quality data was provided by the Waikato Regional Council, and was collected using comparable protocols.

Adult pest fish barrier

A temporary fish barrier was installed in the only outlet to Lake Ohinewai prior to the initial marking and sampling (Figure 6). The temporary barrier consisted of 25 mm mesh stretched over a steel ring that was placed in the south side of the Tahuna Road culvert. High flows and light debris loads caused multiple short-term failures of the barrier, potentially allowing pest fish to enter and exit the lake. Temporary barrier failures did not occur until 1 April and did not influence the population estimate as the estimate was based on data collected prior to April. The drain was monitored to quantify the potential influence of the breach on the overall biomass reduction. Small mesh fyke nets were set on either side of the Tahuna Road culvert to quantify the biomass of fish entering and exiting the lake (11 net nights). Monitoring was discontinued after one of the fyke nets was stolen from the drain on 13 April 2011.

Figure 6. Temporary adult fish barrier installed on the Lake Ohinewai drain on south side of the Tahuna Road culvert 15 January 2011. Photo: A. Daniel.

A permanent adult pest fish barrier was designed by the University of Waikato and constructed by Daniel Hall Engineering to block adult pest fish from entering Lake Ohinewai through the 1400 mm culvert under Tahuna Road (Figure 7). Telemetry tracking of koi carp in the lower Waikato River and riverine lakes has suggested that up to 75% of koi carp will leave lakes at some point in their life history (Daniel et al. 2011). The one-way fish barrier is designed to allow fish to leave the lake but not return potentially reducing the biomass of pest fish in Lake Ohinewai. The barrier was designed with horizontal bars to allow debris <30 mm to pass through unobstructed and was hinged at the top to allow for easy cleaning in the case of blockage. The bar spacing of the one way gate installed in the barrier was based on the fish trap design of Thwaites et al. (2010). Although it is possible for juvenile pest fish to enter Lake Ohinewai it was deemed impractical to design a barrier capable of blocking all pest fish due to the impact on native fish. The bar spacing of 30 mm will likely allow native fish to pass through the barrier in both directions with the assumption that large adult eels will only be passing in the downstream direction (out of the lake). The overall cost of the barrier was approximately $5,000. Monitoring of fish passage and debris loading at the barrier has been scheduled to occur for 10 months beginning in June 2011.

Figure 7. Adam Daniel and Daniel Hall installing the adult pest fish barrier in the Lake Ohinewai drain on the north side of the Tahuna Road culvert 5 May 2011. Photo: A. Gray.

4. Results

Pest fish

Overall 2.7 t of pest fish (koi carp, hybrid, goldfish, catfish and rudd) were removed from Lake Ohinewai (Table 1) and pest fish biomass was reduced from approximately 280.3 kg ha^{-1} to 116.6 kg ha^{-1}. Over 60% of koi carp (2.4 t) were removed from Lake Ohinewai reducing the biomass from over 240 kg ha^{-1} to below 100 kg ha^{-1} (Figure 8 & Appendix A). The combined initial biomass of goldfish (18.9 kg ha^{-1}), catfish (13.13 kg ha^{-1}) and rudd (6.5 kg ha^{-1}) were less than 16% of the 241 kg ha^{-1} estimated for koi carp. Goldfish biomass (7.4 kg ha^{-1}) was reduced by 61% and catfish biomass by 42% to approximately 7.6 kg ha^{-1}. Only 0.6 kg ha^{-1} of rudd were removed, representing a 9% reduction in the estimated initial biomass.

Table 1. Total weight of pest fish removed from Lake Ohinewai 24 January to 2 May 2011

Species	Total weight removed (kg)
Koi carp	2444.4
Goldfish	192.9
Catfish	91.4
Rudd	7.1
Hybrid	2.8
Total	2738.6

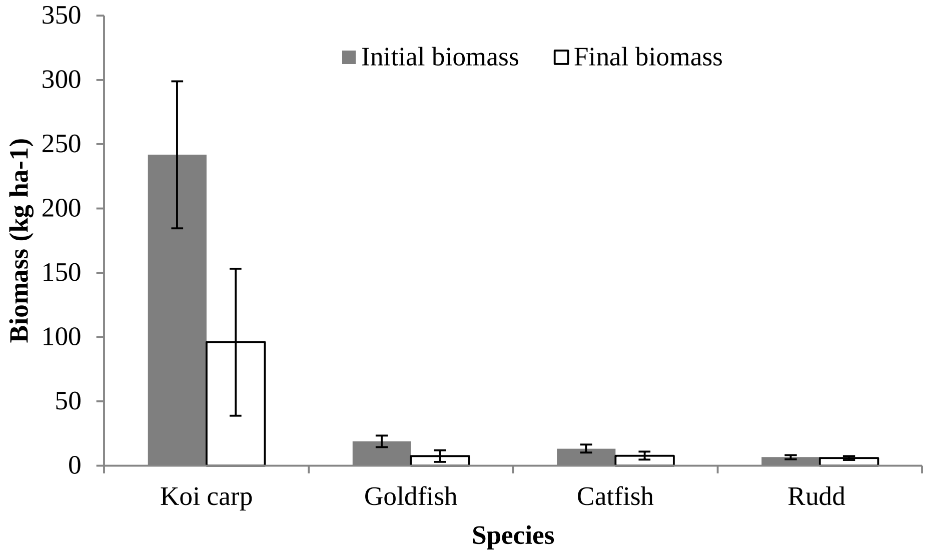

Figure 8. Pre and post removal biomass estimates of koi carp (*Cyprinus carpio*), goldfish (*Cyprinus auratus*), catfish (*Ameiurus nebulosus*), and rudd (*Scardinius erythrophthalmus*) in Lake Ohinewai May 2011. Error bars equal one standard deviation.

The length frequency of pest fish found in Lake Ohinewai (Figure 9) shows a relatively uniform size distribution for most pest species with the exception of rudd where only large adults (150-300 mm) were captured. Although gambusia, *Gambusia affinis*, were present in large numbers, no estimate of biomass or removal was conducted.

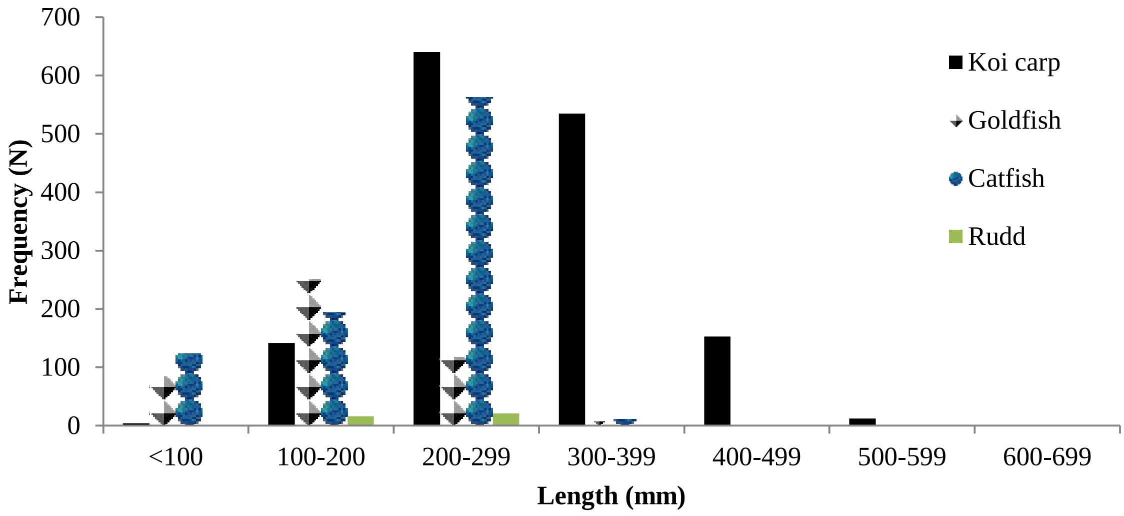

Figure 9. Length frequency of koi carp (*Cyprinus carpio*, N=1491), goldfish (*Cyprinus auratus*, N=461), catfish (*Ameiurus nebulosus*, N=892) and rudd (*Scardinius erythrophthalmus*, N=38) > 75 mm in Lake Ohinewai 17-28 January 2011.

Native fish

The diversity of native fish was limited compared to invasive fish as only shortfin and longfin eels were captured. The native fish population of Lake Ohinewai was dominated by shortfin eels with small catches of longfin eels. Due to water temperatures above 23°C, conducting biomass estimates for native fish was determined to be unethical due to the risk of handling mortality. However, two days of fishing yielded 800 shortfin eels with 95% coming from fyke nets (80 net nights). Shortfin eel lengths ranged from 39-855 mm (Figure 10). Only 18 longfin eels were captured ranging from 320-740 indicating very low numbers of adults were present in Lake Ohinewai and virtually no recruitment was accruing. Although sampling was not specifically designed to detect native fish the extensive fyke net sets, electrofishing and limited minnow trap use (4 net nights) would likely have detected other native fish if present.

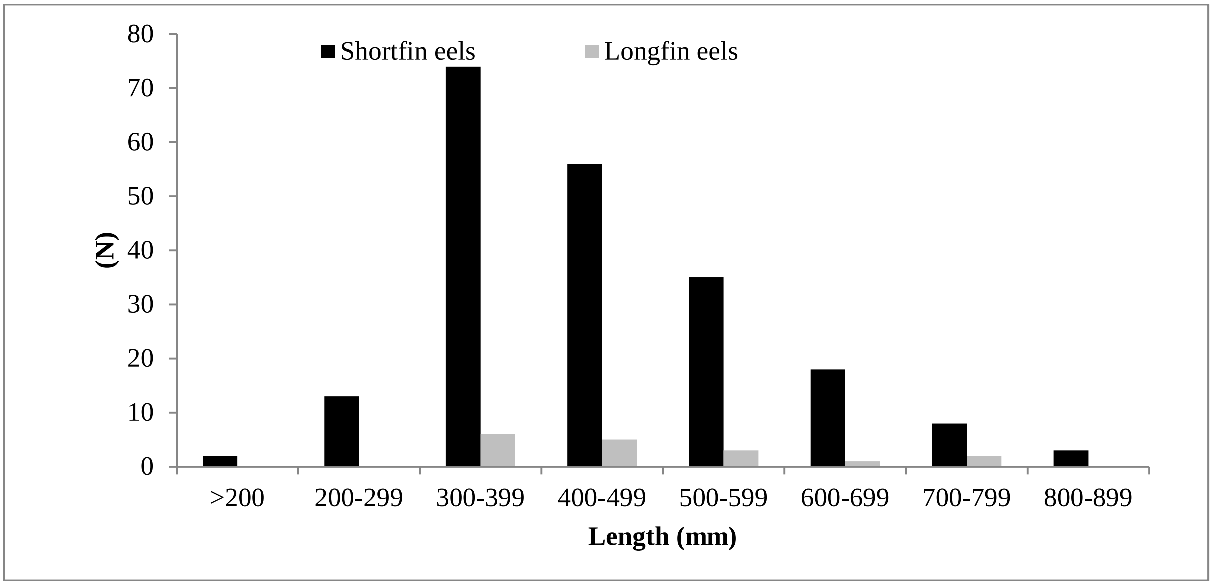

Figure 10. Length distribution of shortfin (*Anguilla australis*, N=800) and longfin eels (*Anguilla dieffenbachii*, N=18) in Lake Ohinewai on 18 and 19 January 2011.

Removal techniques

Baited traps and pen traps were the most effective method for removing pest fish biomass when compared to other methods on a per day basis (Figure 11). Catches from pen traps with feeders approached a mean catch of 60 kg day^{-1}, which included multiple feeder failures that would have artificially decreased their effectiveness. Fyke nets were effective for capturing catfish (17.5 kg day^{-1}) but resulted in large bycatch of eels (shortfin 19.9 kg day^{-1} and longfin 1.3 kg day^{-1}; Figure 11 and 12).

Baited traps (43.8 kg day^{-1}) outperformed unbaited traps (6.1 kg day^{-1}) for capturing koi carp. The only significant catches of fish in unbaited traps were recorded in drains where fish were captured migrating out of the lake. All pest species were represented in trap catches but only 4 rudd (11% of total) and 20 catfish (3% of total) were removed; likely due to the relatively large mesh size of the traps (80 mm) tested. The only bycatch of the traps (including pen traps) was a single eel (~900 mm length) representing 0.03% of the total catch.

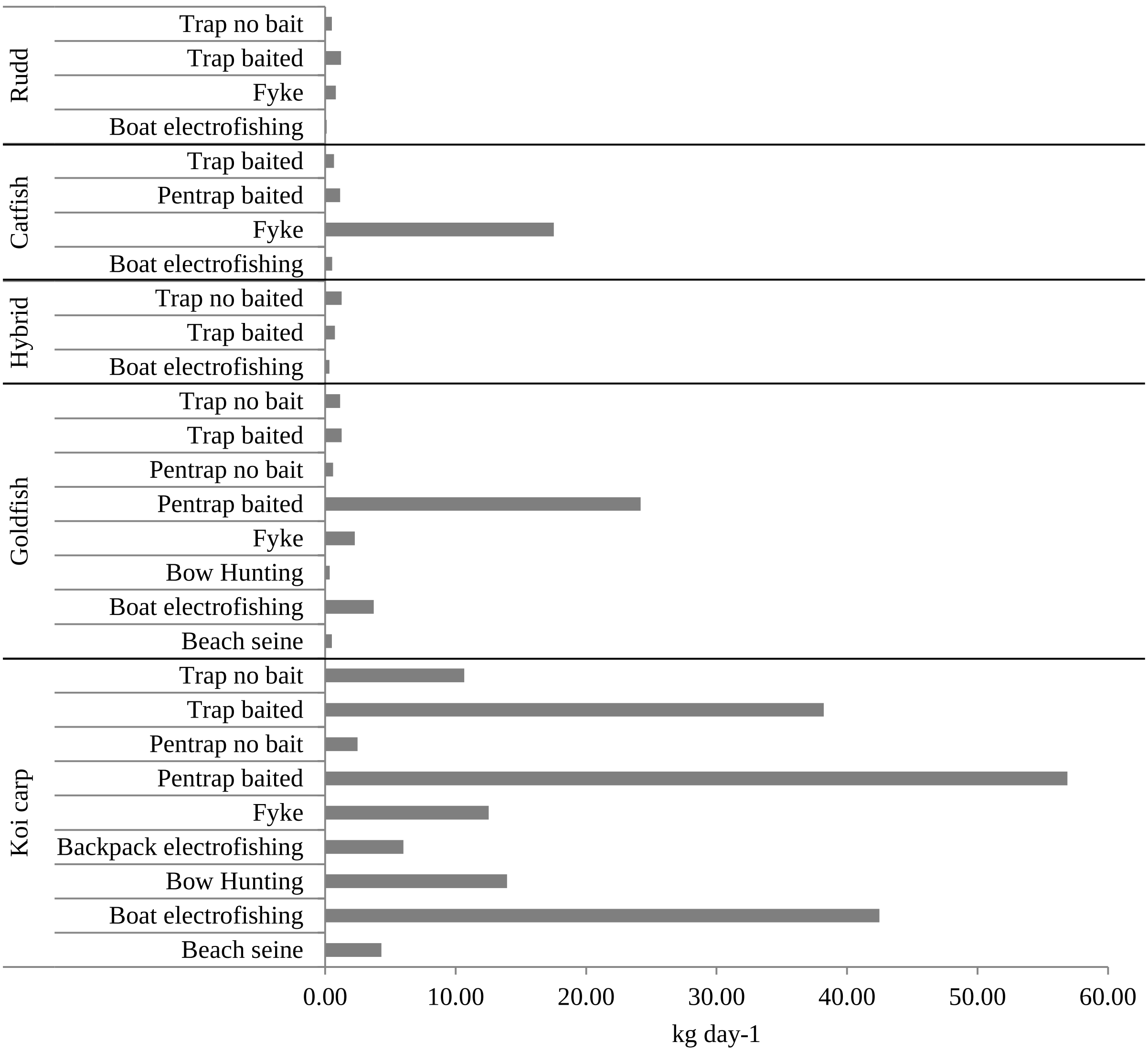

Figure 11. Catch per unit effort for koi carp (*Cyprinus carpio)*, goldfish (*Cyprinus auratus*), hybrid (koi carp X goldfish), catfish (*Ameiurus nebulosus*), rudd (*Scardinius erythrophthalmus*) and tench (*Tinca tinca*) captured in Lake Ohinewai 17-27 January 2011. Catches based on one day of electrofishing, an overnight set of 40 fyke nets, a day of bow hunting, or an overnight set of one trap.

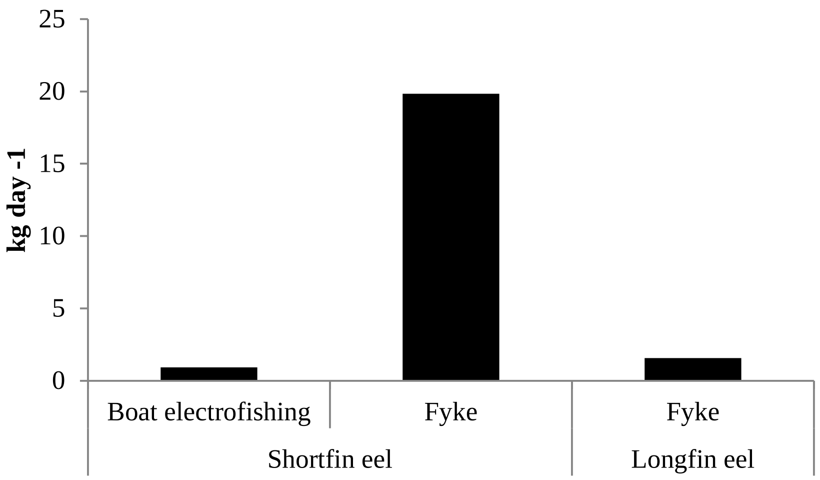

Figure 12. Catch per unit effort for shortfin eel (*Anguilla australis*) and longfin eel (*Anguilla dieffenbachii*) captured in Lake Ohinewai 17-27 January 2011**.** Catches based on one day of boat electrofishing or overnight set of 40 fyke nets.

Water quality

Lake Ohinewai has frequent algal blooms with a phytoplankton community dominated by cyanobacteria with low species diversity. Water quality measures collected near the surface and at depth are presented in Tables 2 and 3. Dissolved oxygen values near the surface and at depth remained relatively constant throughout the 2011 monitoring period. Total and volatile suspended solid levels decreased during and shortly after fish removal. In addition, chlorophyll *a* concentration peaked in late February, when the water temperature was warmest, and then generally declined. Secchi disc depth tended to increase during the 2011 monitoring period. Water column depth ranged between 3.2 - 3.9 m over the sampling period and was negatively influenced by drain cleaning during April 2011. Shortly after vegetation was cleared from the Lake Ohinewai drain (north side of Tahuna Road) water velocity in the drain increased from static to nearly 0.5 m s^{-1}. Within 72 h of drain clearing the lake level dropped by approximately 150 mm.

Although the number of historical data points are relatively few, chlorophyll *a* concentrations and volatile suspended solids data collected near the surface on the water column prior to the pest fish removal were considerably different from post removal (2011 data), and do not follow the same declining trends. While the historical secchi disk depth measurements are not markedly different from the 2011 data, they tend to fluctuate more.

Table 2. Water quality data collected near the surface of Lake Ohinewai. Temperature and dissolved oxygen data were collected at 0.5 m; total suspended solids, volatile suspended solids and chlorophyll *a* data were collected at 0.9 m. 'Early' and 'late' monthly data were collected during the first half of a given month (respectively), and for 2011 data statistics are weekly mean values; however, only one data collection was conducted in early May. 'Historical' data are mean values collected 7/12/06 – 16/3/10 (see footnote).

	Temp. (°C)	Dissolved oxygen (mg L^{-1})	Total suspended solids (g m^{-3})	Volatile suspended solids (g m^{-3})		Chlorophyll *a* (mg m^{-3})		Secchi disc depth (m)	
	2011	**2011**	**2011**	**2011**	**Historical***	**2011**	**Historical***	**2011**	**Historical***
December					9.9[a]		0.047[g]		0.43[a]
Late January		8.66	25.0		21.0[b]	0.063	0.057[b]	0.35	0.22[b]
Early February	23.8	8.58	27.5			0.105		0.36	
Late February	23.9	9.35	33.0			0.167		0.35	
Early March	22.2	8.92	25.5	19.5	8.7[c]	0.131	0.066[c]	0.42	0.54[c]
Late March	20.8	8.67	26.0	17.0	18.0[d]	0.116	0.098[d]	0.41	0.40[h]
Early April	18.7	10.26	18.5	17.0	7.0[e]	0.077	0.033[e]	0.55	0.58[e]
Late April	16.6	10.81	22.0	16.0		0.087		0.52	
Early May	16.2	9.75	20.0	18.0	8.9[f]	0.079	0.050[f]	0.54	0.44[f]

* Historical data provided by the Waikato Regional Council. Historical collection dates: a= 7/12/06, 11/12/07, 11/12/08, 7/12/09; b= 23/1/07; c= 10/3/08; d= 18/3/09; f= 3/4/07; g= 7/12/06, 11/12/07, 11/12/08; h= 18/3/9, 16/3/10.

Table 3. Water quality data collected at depth in Lake Ohinewai in 2011. Temperature and dissolved oxygen data were collected at a depth of 2.0 m; total suspended solids and volatile suspended solids data were collected at 2.7m. 'Early' and 'late' monthly data were collected during the first and second half of a given month (respectively) and are weekly mean values; however, only one data collection was conducted in early May.

	Temperature (°C)	Dissolved oxygen (mg L^{-1})	Total suspended solids (g m^{-3})	Volatile suspended solids (g m^{-3})
Early February	23.0	8.31	28.0	
Late February	23.9	9.19		
Early March	21.7	7.28	27.0	20.5
Late March	20.3	7.33	24.5	18.5
Early April	18.2	8.68	19.0	12.0
Late April	16.5	10.77	20.5	15.5
Early May	15.5	9.08	18.0	12.0

Adult pest fish barrier

There was a small net loss of pest fish over the drain monitoring period with small amounts of koi, catfish and goldfish captured (11 net nights; Table 4). Shortfin eels were captured in relatively large numbers entering the lake (Table 4). Notably, all eels captured were less than 300 mm and would have easily passed through the pest fish barrier with 30-mm bar spacing. The adult pest fish barrier was monitored visually for debris and koi presence. Within a week of installation, larger numbers of adult koi were observed in the drain unsuccessfully attempting to enter the lake (Figure 13). Small amounts of debris did build up on the barrier requiring a monthly cleaning during periods of heavy rain.

Table 4. Drain barrier monitoring conducted 3-15 April 2011 including 11 net nights above and below the temporary drain barrier. Eels were enumerated and no shortfin eels were captured >300 mm in length.

	Koi carp (kg)	Catfish (kg)	Goldfish (kg)	Shortfin eel (N)
Into lake (N side)	1.50	0.22	0.50	34
Out of lake (S side)	1.90	0.81	0.25	4

Figure 13. Approximately 60 koi carp attempting to enter to pass the adult pest fish barrier on the Lake Ohinewai Drain. Photo: A. Daniel.

Cost

The total project cost was approximately $40,000 as of 1 June 2011. The fish removal process was labour intensive and included approximately 1,288 h of manual effort (Table 5). The equipment utilized included 40 fyke nets, 2 large traps, pod-trap, electrofishing boat, sampling boat and sampling equipment with a value in excess of $100,000.

Table 5. Approximate breakdown of labour contributions by agency and phase of the project from Jan-May, 2011. Preparation time and ongoing fishing (after June 1) are not accounted for.

	Marking (h)	**Initial recapture (h)**	**continued fishing (h)**	**Total (h)**
University of Waikato	248	320	624	1192
Department of Conservation	8	24	8	40
Ngaa Muka Development Trust	24	32	0	56
Total	200	376	632	1288

5. Discussion

The Lake Ohinewai fish removal successfully reduced koi carp biomass to <100 kg ha^{-1}. Water quality will continue to be monitored by the University of Waikato as part of the ongoing lake restoration programme. Additional fish removal is planned for the winter 2011 to further reduce the biomass of pest fish in Lake Ohinewai to insure that adequate fish removal has been achieved to detect the potential water quality improvements.

The research and development that occurred during the Lake Ohinewai fish removal was invaluable for future pest fish removal programmes in New Zealand. Adding automated feeders to existing trap designs increased catches by greater than 600% compared to previous removal attempts that used single applications of burly. The additional efficiency of using automated burly machines with traps will likely make koi carp fishing commercially viable potentially reducing the cost of lake restoration for some end users. Baited traps were intentionally tested in locations where koi carp would not be captured due to behaviour such as migration so combining trap placement (i.e., placing traps in front of inlet streams to disperse bait or blocking outlet streams) with bait will likely further increase catch rates. The phenomenally low bycatch of native fish was likely due to large mesh size if smaller mesh size is tested in the future, to increase the size range of pest fish removed, an escape port for eels should be trialled.

Although fyke nets were very effective at removing catfish they were also highly effective at capturing native eels resulting in high bycatch that could lead to mortality in water temperatures above 23 °C. This heat related mortality should be considered when using fyke nets or handling eels in the future.

The cost of the removal was substantial due to the scientific nature of the operation. Most of the labour was used for the comparison of fishing techniques. For example, nearly a month of the fishing was used to perfect the burly delivery system. Due to the valuable information gained during this study similar results could be reach in approximately 1 month of fishing using 4 baited traps cleared 3 days a week by two technicians.

Overall, this programme has made great strides in koi carp removal but has identified concerns with current methods of catfish removal. Although our short term goal of koi carp biomass reduction has been met, the long-term goal of water quality improvement will not be evaluated until April 2012.

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Appendix A. Population and biomass estimates with 95% confidence intervals for pest species at Lake Ohinewai January to April 2011. Population and biomass estimates include koi carp (*Cyprinus carpio*), goldfish (*Cyprinus auratus*), catfish (*Ameiurus nebulosus*), rudd (*Scardinius erythrophthalmus*).

Koi carp	**Lincoln-Petersen**	**95% CI**	
		Lower	Upper
Initial population estimate (N)	6869	5245	8493
Final population estimate (N)	2686	1062	4310
Initial biomass (kg/ha)	241.8	184.6	298.9
Final biomass (kg/ha)	95.9	38.9	153.3

Catfish	**Lincoln-Petersen**	**95% CI**	
		Lower	Upper
Initial population estimate (N)	1629.60	1244.29	2014.91
Final population estimate (N)	950.60	565.29	1335.91
Initial biomass (kg/ha)	13.1	10.0	16.2
Final biomass (kg/ha)	7.7	4.6	10.7

Goldfish	**Lincoln-Petersen**	**95% CI**	
		Lower	Upper
Initial population estimate (N)	844	645	1044
Final population estimate (N)	330	131	530
Initial biomass (kg/ha)	18.9	14.4	23.4
Final biomass (kg/ha)	7.4	2.9	11.9

Rudd	**Lincoln-Petersen**	**95% CI**	
		Lower	Upper
Initial population estimate (N)	396	302	490
Final population estimate (N)	360	266	454
Initial biomass (kg/ha)	6.5	5.0	8.0
Final biomass (kg/ha)	5.9	4.4	7.4